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IMPRINT STAMP

FIELD OF THE INVENTION

The present invention relates generally to a method of fabricating an imprint stamp. More specifically, the present invention relates to a method of fabricating an imprint stamp using controlled thin film deposition processes, lithographic patterning processes, and etching processes to form an the imprint stamp that includes an application specific imprint pattern.

BACKGROUND OF THE ART

Imprint lithography (also referred to as soft lithography) is a promising technique for transferring images from an imprint stamp to a media in which the images are replicated. Unlike current state-of-the-art photolithographic processes which require very expensive process equipment to make masks and to expose a photoresist material with an image on the mask, imprint lithography is a low cost process that eliminates the expensive mask making equipment and lithographic equipment, not to mention the equipment and materials needed to develop and etch the photoresist material. Nano-imprint lithography is a promising technique for obtaining nano-size patterns (as small as a few tens of nanometers or less) in a media. A key step in forming the nano-size patterns in the media is to first form an imprint stamp that includes a pattern that complements the nano-sized patterns that are to be imprinted in the media. Although an imprint stamp can be made to imprint features of any size, imprint stamps with features that are nanometer sized or smaller are of particular interest because of a need to imprint features that are smaller than a lithography limit of current optical base photolithography processes and at a lower cost.

In **FIG. 1a**, a prior nano-imprint lithography process includes an imprint stamp **200** having a plurality of imprint patterns **202** formed thereon. In **FIG. 1b**, the imprint

patterns **202** consists of a simple line and space pattern having a plurality of lines **204** separate by a plurality of spaces **206** between adjacent lines **204**. In **FIG. 1a**, by pressing (see dashed arrow **201**) the imprint stamp **200** onto a mask layer **203**, a thickness of the mask layer **203** is modulated with respect to the imprint patterns **202** such that the imprint patterns **202** are replicated in the mask layer **203**. Typically, the mask layer **203** is made from a material such as a polymer. For example, a photoresist material can be used for the mask layer **203**. The mask layer **203** is deposited on a supporting substrate **205**. Using a step and repeat process, the imprint stamp **200** is repeatedly pressed **201** into the mask layer **203** to replicate the imprint patterns **202** in the mask layer **203** and to cover a desired area of the mask layer **203**.

In **FIG. 2**, after the step and repeat process, the mask layer **203** includes a plurality of nano-size impressions **207** that complement the shape of the imprint patterns **202**. In **FIG. 3**, the mask layer **203** is anisotropically etched (i.e. a highly directional etch) to form nano-sized patterns **209** in the mask layer **203**. Typically, the supporting substrate **205** or another layer (not shown) positioned between the mask layer **203** and the supporting substrate **205** serves as an etch stop for the anisotropic etch. Alternatively, the mask layer **203** can serve as an etch mask for an underlying layer (see reference numeral **208** in **FIGS. 7a** through **7d**) and the pattern of the nano-size impressions **207** is replicated in the underlayer **208** by a subsequent anisotropic etch process.

In **FIG. 4a**, the formation of the imprint patterns **202** on the prior imprint stamp **200** begins by depositing alternating layers of thin film material (**211, 213**) on a substrate **215** to form a multi-stacked thin film **210** that extends outward of a surface **215s** of the substrate **215**. In **FIG. 4b**, the thin film layers (**211, 213**) have thicknesses $\mathbf{t_A}$ and $\mathbf{t_B}$ respectively that can be the same or that can vary. For example, the layer **211** can have a thickness $\mathbf{t_A}$ that is thicker at one level of the multi-stacked thin film **210** and thinner at another level of the multi-stacked thin film **210** as depicted in **FIG. 4b**. Similarly, the layer **213** also has thicknesses $\mathbf{t_B}$ that vary in thickness in the multi-

stacked thin film **210**. Those variations in thickness (**t_A, t_B**) will result in variations in the simple line and space patterns (**204, 206**) in the imprint pattern **202** of the imprint stamp **200** as will be described below in reference to **FIGS. 5a** through **5c**.

In **FIG. 4a**, the multi-stacked thin film **210** is then sliced into a plurality of discrete segments **Δ_S** along a direction shown by dashed arrow **S**. For example, in **FIG. 4c**, the substrate **215** can be a wafer of semiconductor material upon which the multi-stacked thin film **210** is deposited. After all layers of the multi-stacked thin film **210** have been deposited, the wafer (i.e. the substrate **215**) is then sliced, using a saw or the like, to form the discrete segments **Δ_S**.

In **FIG. 5a**, a discrete segment **Δ_S** includes a portion of the multi-stacked thin film **210** and a portion of the substrate **215**. In **FIGS. 5b** and **5c**, the discrete segment **Δ_S** is selectively etched to define the imprint pattern **202**. Differences in etch rates between the alternating layers (**211, 213**) causes one of the layers to be etched at a faster rate than the other layer and results in differences in height between the alternating layers (**211, 213**). Those differences in height define the imprint pattern **202**. Additionally, the differences in the thicknesses (**t_A, t_B**) determines the variations in the widths of the lines **204** and the widths of the spaces **206** of the imprint pattern **202**. The imprint pattern **202** is formed on a portion I_A of the imprint stamp **200** as illustrated in **FIGS. 5b**, **5c**, and **6**. A remaining portion **N_A** of the imprint stamp **200** is a non-patternable area, that is, the portion **N_A** cannot be used for imprinting because that portion of the substrate **215** does not include an imprint pattern.

One disadvantage of the prior imprint stamp **200** is the imprint pattern **202** consists of simple line and space patterns (**204, 206**) as depicted in **FIGS. 6, 7a, 7b, 7c**, and **7d**, wherein, the line and space patterns (**204, 206**) are substantially parallel to each other as denoted by dashed lines **P** in **FIG. 7a**. Consequently, in **FIGS. 7b, 7c**, and **7d**, the resulting nano-size impressions **207** are also limited to simple line **204'** and space **206'** patterns because they complement the line and space patterns (**204,**

206) of the imprint pattern **202** and are therefore also substantially parallel to each other as denoted by dashed lines **P** in **FIGS. 7b** and **7c**.

In **FIG. 7a**, the imprint stamp **200** is pressed **201** onto the mask layer **203** to replicate the simple line **204** and space **206** patterns of the imprint pattern **202** in the mask layer **203**. In **FIG. 7b**, after the pressing step, the mask layer **203** includes the complementary nano-size impressions **207** replicated therein. As was noted above, the nano-size impressions **207** also have the simple line and space pattern denoted as **204'** and **206'** respectively. In **FIG. 7c**, the mask layer **203** is anisotropically etched until the space patterns **206'** are coincident with an upper surface **208'** of an underlayer **208** and the line patterns **204'** extend outward of the upper surface **208'**. The line and space patterns (**204', 206'**) will serve as an etch mask for a subsequent anisotropic etch step. Next, in **FIG. 7d**, the underlayer **208** is anisotropically etched through the mask created by the line and space patterns (**204', 206'**) to define the nano-size patterns **209** that complement the simple line and space patterns (**204, 206**) of the imprint stamp **200**. The nano-size patterns **209** occupy a patterned area $\mathbf{P_A}$ of the substrate **205**; whereas, a remainder of the substrate **205** comprises an unpatterned area $\mathbf{U_A}$.

Consequently, there exists a need for an imprint stamp that includes an application specific imprint pattern comprising complex patterns and shapes. There is also a need for an imprint stamp that includes an application specific imprint pattern that includes feature sizes that are smaller than a minimum resolution of a lithography system used in fabricating the imprint stamp. Furthermore, there is a need for an imprint stamp that includes an application specific imprint pattern that includes feature sizes that are of nanometer dimensions or less.

SUMMARY OF THE INVENTION

The imprint stamp of the present invention solves the aforementioned disadvantages and limitations. The imprint stamp includes complex patterns and shapes that are defined by a plurality of thin film layers. The imprint stamp can include complex patterns and shapes that have feature sizes that are of nanometer dimension or less, because the thin film layers that are used to form the features can have thickness that are a few nanometers or less. The thin film layers include variations in a topography so that each layer can include one or more segments that are non-planar. Those variations in topography taken individually or in combination with the variations in topography of some or all of the other thin film layers define an application specific imprint pattern that includes complex patterns and valuable shapes unlike prior imprint stamps in which the pattern consisted of simple line and space patterns formed by substantially planar layers of material.

An imprint stamp fabricated according to the method described herein provides for a higher imprint pattern density (i.e a ratio of the area occupied by the pattern to a total area of the imprint stamp) and provides for complex imprint patterns as opposed to the simple line and space patterns of prior imprint stamps.

Other aspects and advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings, illustrating by way of example the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. 1a and **1b** are profile and top plan views respectively of a prior imprint stamp that includes simple line and space imprint patterns.

FIG. 2 is a profile view of a prior mask layer with simple line and space impression formed therein by the prior imprint stamp of **FIG. 1a**.

FIG. 3 is a profile view of the prior mask layer of **FIG. 2** after an anisotropic etch step.

FIG. 4a is a cross-sectional view of a prior process for forming a prior imprint stamp.

FIG. 4b is a detailed cross-sectional view of a section V–V of **FIG. 4a** and depicts layers of the prior imprint stamp that are of differing thicknesses.

FIG. 4c is a profile view of a prior substrate prior to being sliced into discrete segments.

FIGS. 5a through **5c** are cross-sectional views of a discrete segment of a prior imprint stamp that has been selectively etched to define simple line and space imprint patterns.

FIG. 6 is a profile view depicting an imprint area and a non-patternable area of the prior imprint stamp.

FIGS. 7a through **7d** depict a prior process for pressing the prior imprint stamp into a prior mask layer to form patterns therein.

FIG. 8a is a flow diagram depicting a method of making an imprint stamp.

FIG. 8b is a flow diagram depicting an alternative method of making an imprint stamp.

FIGS. 9a and **9b** are cross-sectional views depicting a substrate.

FIG. 9c is a top plan view depicting a wafer substrate.

FIG. 10 is a cross-sectional view depicting a patterning and an etching of a substrate.

FIG. 11 is a cross-sectional view depicting a patterned substrate.

FIG. 12a is a cross-sectional view depicting a depositing of a first layer of material on a patterned substrate.

FIG. 12b is a cross-sectional view depicting a first layer of material after a planarization process.

FIG. 12c is a cross-sectional view depicting a patterning and an etching of a first layer of material.

FIG. 12d is a cross-sectional view depicting a pattern formed in a first layer of material and including variations in a topography of the first layer of material.

FIG. 13a is a cross-sectional view depicting a depositing of an additional layer of material on a previously deposited layer of material.

FIG. 13b is a cross-sectional view depicting a patterning and an etching of an additional layer of material.

FIG. 13c is a cross-sectional view depicting a pattern formed in an additional layer of material and including variations in a topography of the additional layer of material.

FIG. 14a is a cross-sectional view depicting a depositing of an additional layer of material on previously deposited layers of material.

FIG. 14b is a cross-sectional view depicting a patterning and an etching of an additional layer of material.

FIG. 14c is a cross-sectional view depicting a pattern formed in an additional layer of material and including variations in a topography of the additional layer of material.

FIGS. 15a and **15b** are cross-sectional views depict respectively a depositing of an additional layer of material on previously deposited layers of material and a pattern formed in the additional layer of material and including variations in a topography of the additional layer of material.

FIGS. 16a and **16b** are cross-sectional views depict respectively a depositing of an additional layer of material on previously deposited layers of material and a pattern formed in the additional layer of material and including variations in a topography of the additional layer of material.

FIGS. 17a and **17b** are cross-sectional views depict respectively a depositing of an additional layer of material on previously deposited layers of material and a pattern formed in the additional layer of material and including variations in a topography of the additional layer of material.

FIGS. 18a and **18b** are cross-sectional views depict respectively a depositing of an additional layer of material on previously deposited layers of material and a pattern formed in the additional layer of material and including variations in a topography of the additional layer of material.

FIG. 19a is a top plan view depicting a substrate including a plurality of segment lines.

FIG. 19b is a profile view depicting a plurality of segment lines for a discrete segment of a substrate.

FIG. 19c is a cross-sectional view of a discrete segment that includes a plurality of layers of material including variations in a topography of the layers of material that define an application specific imprint pattern.

FIG. 19d is a top plan view depicting an imprint blank .

FIG. 19e is profile view depicting an imprint blank.

FIGS. 19f and **19g** are profile views of an imprint stamp.

FIG. 19h is profile view depicting a plurality of imprint stamps connected with a master substrate.

FIGS. 20a through **20c** are top plan views depicting an imprint stamp formed from an imprint blank and including an application specific imprint pattern.

FIG. 21 is a cross-sectional view along line IV–IV of **FIG. 20c** and depicts an imprint blank before a selective etching process.

FIG. 22a is a cross-sectional view depicting a selective etching of a layer of material in an imprint blank.

FIG. 22b is a cross-sectional view depicting an imprint stamp formed by the etching process of **FIG. 22a**.

FIG. 23a is a cross-sectional view depicting a selective etching of a layer of material in an imprint blank.

FIG. 23b is a cross-sectional view depicting an imprint stamp formed by the etching process of **FIG. 23a**.

FIG. 24 is a cross-sectional view depicting an imprint stamp and a mask layer being urged into contact with each other.

FIG. 25 is a cross-sectional view depicting the imprint stamp pressed into the mask layer of **FIG. 24**.

FIGS. 26 through **28** are cross-sectional views depicting an etching of a mask layer.

FIG. 29 is a cross-sectional view depicting a depositing of a target media on an imprinted pattern formed in a mask layer.

FIG. 30a is a cross-sectional view depicting a patterned substrate.

FIG. 30b is a cross-sectional view depicting a depositing of a conformal layer of material on the patterned substrate of **FIG. 30a**.

FIG. 30c is a cross-sectional view depicting a depositing of a first layer of material on a conformal layer of material.

FIG. 31a is a cross-sectional view depicting a base layer of material deposited on a substrate.

FIG. 31b is a cross-sectional view depicting a base layer of material after a patterning and an etching of the base layer of material.

FIG. 31c is a cross-sectional view depicting a depositing of a conformal layer of material on a patterned base layer of material.

FIG. 31d is a cross-sectional view depicting a depositing of a first layer of material on a patterned base layer of material.

DETAILED DESCRIPTION

As shown in the drawings for purpose of illustration, the present invention is embodied in a method of fabricating an imprint stamp. In **FIG. 8a**, a first embodiment of a method of fabricating an imprint stamp includes patterning **80** a substrate and then etching **81** the substrate to form a pattern in the substrate. A first layer of material is deposited **82** on the substrate. The first layer of material is patterned **83** and then etched **84** to form a portion of an application specific imprint pattern in the first layer of material. The portion of the application specific imprint pattern includes a variation in a topography of the first layer of material. An additional layer of material is deposited **85** on a previously etched layer of material (e.g. the first layer of material). The additional layer of material is patterned **86** and then etched **87** to form an additional portion of the application specific imprint pattern in the additional layer of material. The additional portion the application specific imprint pattern includes a variation in a topography of the additional layer of material. The depositing of additional layers of material **85**, the patterning **86**, and the etching **87** are repeated **88** until the application specific imprint pattern is completely defined and comprises a plurality of features that are defined by the variations in the topographies of all of the layers of material that were deposited (**81', 82, 85**) patterned (**80, 83, 86**), and etched (**81, 84, 87**). The substrate is segmented **89** to form an imprint blank that includes the application specific imprint pattern on an exposed cross-sectional surface of the imprint blank. The exposed cross-sectional surface of the imprint blank is selectively etched **90** to form an imprint stamp. Optionally, after the etching **81** of the substrate, a conformal layer of material is deposited **81'** on the substrate. As another option, after the first layer of material is deposited **82**, the first layer of material can be planarized **82'**. As yet another option, after the application specific imprint pattern is completely defined **88**, a last of the additional layers of material is planarized **88'**.

In **FIG. 8b**, a second embodiment of a method of fabricating an imprint stamp includes depositing **92** a base layer of material on a substrate. The base layer of material is patterned **93** and then etched **94** to form a pattern in the base layer of material. A first layer of material is deposited **95** on the base layer of material. The first layer of material is patterned **96** and then etched **97** to form a portion of an application specific imprint pattern in the first layer of material. The portion of the application specific imprint pattern includes a variation in a topography of the first layer of material. An additional layer of material is deposited **98** on a previously etched layer of material (e.g. the first layer of material). The additional layer of material is patterned **99** and then etched **100** to form an additional portion of the application specific imprint pattern in the additional layer of material. The additional portion the application specific imprint pattern includes a variation in a topography of the additional layer of material. The depositing of additional layers of material **98**, the patterning **99**, and the etching **100** are repeated **101** until the application specific imprint pattern is completely defined and comprises a plurality of features that are defined by the variations in the topographies of all of the layers of material that were deposited (**94', 95, 98**), patterned (**93, 96, 99**), and etched (**93, 97, 100**). The substrate is segmented **102** to form an imprint blank that includes the application specific imprint pattern on an exposed cross-sectional surface of the imprint blank. The exposed cross-sectional surface of the imprint blank is selectively etched **103** to form an imprint stamp. Optionally, after the etching **94** of the base layer of material, a conformal layer of material is deposited **94'** on the base layer of material. As another option, after the first layer of material is deposited **95**, the first layer of material can be planarized **95'**. As yet another option, after the application specific imprint pattern is completely defined **101**, a last of the additional layers of material is planarized **101'**.

In **FIG. 9a**, a substrate **11** can include a surface **11s** and a bottom surface **12b**. Preferably, the surface **11s** and the bottom surface **12b** are substantially planar surfaces. The substrate **11** can be made from a material including but not limited to a glass, a heat and chemical resistant glass such as a borosilicate glass (e.g. a **PYREX®** borosilicate glass), a silicon oxide (**SiO_2**), a silicon nitride (**Si_3N_4**), an

aluminum oxide (**Al_2O_3**), an indium phosphide (**InP**), and a semiconductor material. The semiconductor material can be a material including but not limited a wafer of a semiconductor material, silicon (**Si**), and a silicon wafer. The silicon can be single crystal silicon (**Si**).

In **FIG. 9b**, the substrate **11** can be connected with a handling substrate **9**. The handling substrate **9** can be made from a material including but not limited to the materials listed above for the substrate **11**. The substrate **11** can be deposited or grown on the handling substrate **9**. For example if the substrate **11** is silicon oxide (**SiO_2**) and the handling substrate **9** is made from silicon (**Si**), then the silicon oxide (**SiO_2**) can be grown on a surface **9s** of the handling substrate **9** using an oxidation process comprising oxygen (**O_2**) to form the silicon oxide (**SiO_2**). Optionally, after the oxidation process, the surface **11s** can be planarized using a process including but not limited to chemical mechanical planarization (CMP) in order to obtain a substantially planar surface. As will be described below, a substantially planar surface is desirable for subsequent patterning steps. Preferably, the surface **9s** and a bottom surface **9b** of the handling substrate **9** are substantially planar surfaces.

As described above, in **FIG. 9c**, the substrate **11** can be a wafer of a semiconductor material (e.g. silicon **Si**) such as the type used as a starting material for microelectronic devices. The wafer can include a wafer flat **11f**. The surface **11s** may be inherently flat or the surface **11s** can be planarized to form a substantially planar surface. One of ordinary skill in the art will appreciate that the handling substrate **9** can also be a silicon wafer and the substrate **11** can be deposited or grown on the handling substrate **9** as was described above. One advantage to using a wafer of a semiconductor material is that the surfaces (**11s, 12b, 9s,** and **9b**) are typically substantially planar surfaces formed during a manufacturing of the wafer. Moreover, as will be described below, one or more of the substrates **11** can be connected with a master substrate at a later stage in the fabrication of the imprint stamp.

In **FIG. 10** and referring to **FIG. 8a**, at a stage **80**, the substrate **11** is patterned. The patterning can be accomplished using photolithographic processes that are well understood in the microelectronics art. For example, a photoresist material **25** can be deposited on the surface **11s** and then exposed through a mask (not shown) to transfer a pattern to the photoresist material **25**. After the exposing, the photoresist material **25** is then developed to render the pattern. Consequently, some portions of the surface **11s** will be covered by the photoresist material **25**; whereas, other portions of the surface **11s** will not be covered by the photoresist material **25**. Those portions of the photoresist material **25** that remain define an etch mask. Hereinafter, the etch mask will be denoted as reference numeral **25** and other layers of material that will be described below can be patterned and etched in a manner similar to the substrate **11**.

In **FIG. 10**, at a stage **81** the substrate **11** is etched **e** to form a pattern in the substrate **11**. In **FIG. 11**, the pattern can include trenches **11t** formed in the substrate **11** and extending inward of the surface **11s**. The patterns formed in the substrate **11** will have a feature size that is greater than or equal to a minimum resolution $\boldsymbol{\lambda_L}$ of the lithographic system that was used to pattern the substrate **11**.

In **FIG. 12a**, at a stage **82**, a first layer of material **13** is deposited on the substrate **11**. The first layer of material **13** is one of a plurality of layers of material that will be deposited in a deposition order $\mathbf{D_O}$. In **FIG. 12c**, at a stage **83**, the first layer of material **13** is patterned with an etch mask **25**. At a stage **84** the first layer of material **13** is etched **e** form a portion of an application specific imprint pattern in the first layer of material **13**. The portion includes a variation in a topography of the first layer of material **13**.

In **FIG. 12d**, the variations in the topography of the first layer of material **13** can include discrete segments of the first layer of material **13** created by the etching **e** at the stage **84**. Some of the discrete segments **13** fill the trenches **11t** and extend outward of the surface **11s** and some of the discrete segments **13** are disposed on the

surface **11s**. For example, an L-shaped discrete segment **13** that includes a portion disposed in the trench **11t** and a portion that is disposed on the surface **11s**. Moreover, the variations in the topography includes variations in a thickness $\mathbf{t_F}$ of the discrete segments **13**.

For example, the L-shaped discrete segment **13** includes the portion disposed on the surface **11s** and having a thickness $\mathbf{t_F}$ that is less than a thickness $\mathbf{t_F}$ of the portion that is disposed in the trench **11t**. Consequently, the discrete segment **13** is non-planar. That is, the discrete segment **13** is not substantially planar across an entirety of the substrate **11** and can include some portions that are planar and other portions that are non-planar so that taken as a whole, the discrete segment **13** is non-planar.

Optionally, in **FIGS. 12a** and **12b**, prior to the patterning at the stage **83**, at a stage **82'**, the first layer of material **13** can be planarized to form a substantially planar surface **13s**. For example, a process such as CMP can be used to planarize the first layer of material **13**. The first layer of material **13** can be planarized along a line I–I. The line I–I can run parallel to the surface **11s**. In some applications, it may be desirable to have a substantially planar surface upon which to deposit and lithographically pattern the material that will be used for the etch mask **25**. Planarization is particularly effective at removing a depression **13d** (see **FIG. 12a**) that is formed over the trench **11t** during the depositing of the first layer of material **13**.

However, because the portion of the application specific imprint pattern in the first layer of material **13** includes the variation in the topography of the first layer of material **13**, it may be desirable to allow the depressions **13d** to remain so that the depressions **13d** are a part of the variation in the topography of the first layer of material **13**. Moreover, as will be described below, when additional layers of material are deposited over the first layer of material **13**, the depressions **13d** can be used to form variations in the topography of those additional layers of material so that the

application specific imprint pattern is intended to include a topographical effect caused by the depressions **13d** in the first layer of material **13** and in the additional layers of material that are subsequently deposited in the deposition order $\mathbf{D_O}$. For example, if the additional layers of material are very thin, then the topographical effect caused by the depressions **13d** can propagate into several layers of the additional layers of material (see **13d** and **15d** in **FIG. 31c**). During the patterning of the additional layers of material, the etch mask **25** can be positioned to prevent the depressions (**13d, 15d,** etc.) from being etched away during the etching process **e**.

In **FIG. 13a**, at a stage **85**, an additional layer of material **15** is deposited on a previous etched layer of material. In **FIG. 13a**, the previously etched layer of material is the first layer of material **13**; however, the previously etched layer of material can be any layer of material that was previously deposited, patterned, and then etched in the deposition order $\mathbf{D_O}$. In **FIG. 13b**, at a state **86**, the additional layer of material **15** is patterned with an etch mask **25**. At a stage **87**, the additional layer of material **15** is etched **e** to form an additional portion of the application specific imprint pattern in the additional layer of material **15**. The additional portion includes a variation in a topography of the additional layer of material **15**.

In **FIG. 13c**, the variations in topography can include discrete segments of the additional layer of material **15** and variations in a thickness $\mathbf{t_F}$ of the discrete segments **15**. The variations in topography can also include one or more discrete segments **15** in which at least a portion **15'** of the discrete segment **15** includes an angular or arcuate shape. That is, the discrete segments **15** has variations in topography **15'** and thickness $\mathbf{t_F}$ that result in the discrete segments **15** being non-planar.

In **FIG. 14a**, at a stage **88**, the application specific imprint pattern is not completely defined, accordingly, the stage **85** is repeated, and an additional layer of material **13** is deposited on a previous etched layer of material. Although the additional layer of material is denoted as **13**, the additional layer of material need not be the same

type of material that was used for the first layer of material **13**. In **FIG. 14b**, at a stage **86**, the additional layer of material **13** is patterned with an etch mask **25**. At a stage **87**, the additional layer of material **13** is etched **e** to form an additional portion of the application specific imprint pattern in the additional layer of material **13**. As described above, the additional portion includes a variation in a topography of the additional layer of material **13**.

In **FIG. 14c**, the variations in topography can include discrete segments of the additional layer of material **13** and variations in a thickness $\mathbf{t_F}$ of the discrete segments **13**. The variations in topography can also include one or more discrete segments **13** in which at least a portion **13'** of the discrete segment **13** includes an angular or arcuate shape so that the discrete segments **13** includes variations in topography **13'** and thickness $\mathbf{t_F}$ that result in the discrete segments **13** being non-planar.

In **FIGS. 15a** through **18b**, the depositing of additional layers of material (**13, 15**) at the stage **85**, the patterning (not shown) at the stage **86**, and the etching (not shown) at the stage **87** are repeated until the application specific imprint pattern is completely defined at the stage **88** and the application specific imprint pattern includes a plurality of features that are defined by the variations in the topographies of all of the layers of material (**13, 15**) that were deposited, patterned, and etched as described above.

In **FIGS. 17b** and **18b**, some of the additional layers of material (i.e. **15** and **13** respectively) that define the plurality of features in the application specific imprint pattern include a minimum a feature size $\boldsymbol{\lambda_F}$ that is less than the minimum resolution $\boldsymbol{\lambda_L}$ (i.e. $\boldsymbol{\lambda_F < \lambda_L}$). The actual dimensions for the minimum a feature size $\boldsymbol{\lambda_F}$ will be application specific. However, for some applications it is desirable for the minimum feature size $\boldsymbol{\lambda_F}$ to be of a sub-micron scale (i.e. less than about 1.0 μm) and in other applications it is desirable for the minimum feature size $\boldsymbol{\lambda_F}$ to be of a nanometer scale (i.e. less than about 100.0 nm). For example, the minimum feature size $\boldsymbol{\lambda_F}$ can be less than about 10.0 nm.

In **FIGS. 19a** and **19b**, at a stage **89**, the substrate **11** is segmented to form an imprint blank **50** (see **FIGS. 19d, 19e, 21, 22a,** and **23a**) that includes the application specific imprint pattern. The substrate **11** can be partitioned into a plurality of individual segments $\mathbf{\Delta_T}$ that include an exposed cross-sectional surface (**33, 35**). The partitioning can be accomplished by a process including but not limited to sawing, cutting, slicing, scribing, or the like. For example, if the substrate **11** is a wafer, then the wafer can be sliced or sawed along a scribe line **30s** to form the individual segments $\mathbf{\Delta_T}$ that include the exposed cross-sectional surfaces (**33, 35**). Preferably, the substrate **11** is partitioned (e.g. sliced or sawed) along a direction that is substantially perpendicular to a surface of the substrate **11** (e.g. the bottom surface **12b**). In **FIG. 19c**, each of the individual segments $\mathbf{\Delta_T}$ will include all of the layers of material (denoted as **31**) that were deposited, patterned, and etched on the exposed cross-sectional surface (**33, 35**) of the imprint blank **50**. The layers of material **31** includes the layers **13** and **15** as described above.

Optionally, after the application specific imprint pattern is completely defined at the stage **88**, at a stage **88'**, a last of the additional layers of material to be deposited in the deposition order $\mathbf{D_O}$ can be planarized so that the last of the additional layers of material has a substantially planar surface. For example, in **FIG. 19c**, the last of the additional layers of material is a layer **15** and the last layer **15** can be planarized along a line I–I. A process including but not limited to CMP can be used for the planarization at the stage **88'**. In **FIGS. 20a** and **20b**, the planarization the last of the additional layers of material can be used to form a top surface **12t** that is substantially planar. Preferably, the top surface **12t** is substantially parallel to the bottom surface **12b** of the substrate **11**. Prior to the partitioning of the substrate **11**, the substrate **11** can be ground or polished to make the substrate **11** thinner before it is diced into the individual segments $\mathbf{\Delta_T}$. For example, a back-grinding process can be used to thin the substrate **11**. The substrate **11** may also be polished or otherwise planarized so that the bottom surface **12b** is substantially flat and is substantially parallel to the top surface **12t**.

In **FIGS. 19d** and **19** , after the partitioning, an imprint blank **50** is formed and includes the layers of material **(13, 15)** on exposed surfaces **(33, 35)**. Preferably, the exposed cross-sectional surfaces **(33, 35)** are polished using a process such as CMP so that those surfaces are smooth and substantially planar along a dashed line II–II in preparation for a selective etch of the layers of material **(13, 15)** as will be described below.

In **FIG. 19f**, the layers **15** on the exposed cross-sectional surface **33** are selectively etched so that the layers **13** stand in relief (i.e. the layers **13** extend outward of the layers **15**) and form an imprint stamp **10** that includes an imprint pattern comprising a plurality of contact pads **21** and a plurality of wires **23** connected with the contact pads **21**. The substrate **11** depicted in **FIGS. 19a**, **19b**, and **19c** can yield more than one imprint stamp **10** and those imprint stamps **10** can be used individually in a imprint or soft-lithography process or those imprint stamps **10** can be connected with a master substrate in an orderly pattern such as an array or in some other pattern. The imprint blanks **50** can be connected with the master substrate and then the exposed cross-sectional surfaces **33** or **35** can be selectively etched as described above.

Accordingly, in **FIG. 19g** an adhesive, glue, or the like can be applied to the exposed cross-sectional surface **35** of the imprint stamp **10**. Subsequently, in **FIG. 19h**, a plurality of imprint stamps **10** can be connected with a surface **41t** of a master substrate **41**. The imprint stamps **10** can be arranged in an orderly pattern such as in rows and columns of an array or in an irregular pattern. A precision pick-and-place machine can be used to accurately position the imprint stamps **10** on the surface **41t**. Suitable materials for the master substrate **41** include but are not limited to a metal, a metal alloy, a glass, a heat and chemical resistant glass such as a borosilicate glass (e.g. a **PYREX®** borosilicate glass), a ceramic, a composite material, quartz, a semiconductor material, sapphire, and silicon (**Si**).

In **FIG. 19h**, a bottom surface **41b** of the master substrate **41** can be connected with an imprint lithography system (not shown) and then used in an imprint lithography process to imprint a media (not shown) with the application specific imprint patterns carried by the imprint stamps **10**. The imprint stamps **10** that are connected with the master substrate **41** need not be of the same size or the same shape, and the application specific imprint pattern can vary among the imprint stamps **10**.

In **FIG. 20a**, an imprint stamp **10** includes an application specific imprint pattern **40** (shown in dashed line) formed on the exposed cross-sectional surface **33**. The imprint stamp is formed from the imprint blank **50**. The application specific imprint pattern **40** includes a plurality of features that are defined by the variations in topography of the layers of material (**13, 15**) that were deposited, patterned, and etched as described above. For example, the layers **13**, as will be described in greater detail below in reference to **FIGS. 20b** and **20c**, include complex shapes and patterns that define a contact pad pattern and a wire pattern that is connected with the contact pad pattern. For example, the pattern for the wires includes some planar segments and other segments that are non-planar. Similarly, the layers **15** define an area that separates the wire and contact pad patterns from one another and the layers **15** also include complex shapes and patterns. For instance, the layers **15** includes some planar segments and other segments that are non-planar.

The layers **13** and **15** can also include the minimum feature size $\boldsymbol{\lambda}_F$. For example, the wires **13** can be 6.0 nm wide and a space **15** between the wires **13** can 5.0 nm wide. Furthermore, the pattern for the contact pads **13** can include a feature size $\boldsymbol{\lambda}$ that can be greater than or equal to the minimum resolution $\boldsymbol{\lambda}_L$ (that is $\boldsymbol{\lambda} \geq \boldsymbol{\lambda}_L$). On the other hand, the feature size $\boldsymbol{\lambda}$ can be less than the minimum resolution $\boldsymbol{\lambda}_L$ (that is $\boldsymbol{\lambda} < \boldsymbol{\lambda}_L$) as will be described below in reference to a conformal layer of material **12** in **FIGS. 30a** through **31d**.

In **FIGS. 20b** and **20c**, at a stage **90**, the exposed cross-sectional surface (**33, 35**) of the imprint blank **50** is selectively etched **e** to form an imprint stamp **10**. Although either one or both of the exposed cross-sectional surfaces (**33, 35**) can be selectively etched, typically only one of the surfaces is selectively etched. For purposes of illustration, the exposed cross-sectional surface **33** is selectively etched. The selective etching process can be an anisotropic etching process and the etch material can be selective to one or more of the layers of material **31**. The etching process can be a anisotropic etch process (e.g. a plasma etch). For example, a reactive ion etching process (RIE) can be used.

In **FIG. 20b**, the imprint stamp **10** includes the application specific imprint pattern **40**. Although the actual application specific imprint pattern **40** will be determined by the application, in **FIGS. 20b** and **20c**, the plurality of features comprising the application specific imprint pattern **40** includes a contact pad **21** and a wire **23** connected with the contact pad **23**. The plurality of features (e.g. **23**) can include the minimum feature size $\boldsymbol{\lambda}_F$ and the minimum feature size $\boldsymbol{\lambda}_F$ can be less than about 10.0 nm. Moreover, the plurality of features include at least a portion **25** that is non-planar. For example, the wire **23** includes bends and angular portions denoted as **25**. As a result, the plurality of features in the application specific imprint pattern **40** can include non-planar and complex features unlike prior imprint stamps wherein the features are substantially planar and differences in the feature size are controlled by deposition thickness. Consequently, variations in the imprint pattern of the prior imprint stamp consists of variations in thickness among the substantially planar layers.

In **FIG. 20c**, the imprint stamp **10** includes the plurality of features in the application specific imprint pattern **40**; however, the plurality of features are less complex than those in **FIG. 20b**. For example, the wires **23** have substantially planar portions but also include non-planar portions denoted as **25** where the wires **21** either bend or connect with the contact pads **21**. In **FIGS. 20b** and **20c**, although the layers **13** are referred to as wires **23** and contact pads **21**, the application specific imprint pattern **40** formed by the layers **13** will be used in a subsequent imprinting process to

form actual electrically conductive contact pads and wires. Accordingly, the layers **13** as formed on the imprint stamp **10** may be made from a dielectric material.

In **FIG. 21**, a cross-sectional view of the imprint blank **50** along line **A-A** of **FIG. 20c** depicts the layers of material **31** in the application specific imprint pattern **40** in relationship to the plurality of features. For instance, the layer of material **13w** corresponds to the wires **23**; whereas the layers of material **13c** corresponds to the contact pads **21**. The layers of material **15** are positioned in between the layers **13w** and **13c** that define the wires **23** and contact pads **21**.

In **FIG. 22a**, at the stage **90**, the selective etching **e** of the imprint blank **50** includes applying an etch material that is selective to only some of the layers of material (e.g. the layer **15**). In **FIG. 22b**, after the selective etching is completed, those layers of material (e.g. the layers **13c** and **13w**) that were not selectively etched stand proud of those layers that were selectively etched (e.g. the layers **15**) because the layers that were selectively etched have receded below the exposed cross-sectional surface **33**. As a result, the layers **13c** and **13w** that define the contact pads **21** and the wires **23** of the imprint stamp **10** are substantially flush with the dashed line II–II. The dashed line II–II is for reference only and is depicted as substantially flush with the exposed cross-sectional surface **33**.

Conversely, in **FIG. 23a**, the layers **13c** and **13w** of the imprint blank **50** are selectively etched **e** so that after the etching, in **FIG. 23b**, the layers **13c** and **13w** that define the contact pads **21** and the wires **23** of the imprint stamp **10** recede below the exposed cross-sectional surface **33**. Consequently, the layers **15** of the imprint stamp **10** stand proud of the layers **13c** and **13w** as indicated by the dashed line II–II because the dashed line II–II is substantially flush with the layers **15**; whereas, the layers **13c** and **13w** are recessed below the dashed line II–II.

In **FIG. 24**, after the selective etching, the imprint stamp **10** (as depicted in **FIG. 22b**) can optionally be connected with a master substrate **41**, as was described above in reference to **FIGS. 19g** and **19h**, in preparation for an imprinting process. As one example, an imprint media **70** that includes a substrate layer **75**, a mask layer **71** with a surface **71s**, and optionally, an under layer **73**, is urged **U** into contact with the imprint stamp **10** by applying a force **F** to the imprint stamp **10** and/or the imprint media **70**. Preferably, the surface **71s** is a substantially planar surface.

In **FIG. 25**, after the application specific imprint pattern **40** has been pressed into the mask layer **71**, the mask layer **71** is modulated **m** with respect to the features **21**, **23**, and **15** of the imprint stamp **10** so that the mask layer **71** includes an imprinted pattern I_P that complements the application specific imprint pattern **40**. The substrates (**41, 75**) can be made from materials including but not limited to the same materials described above for the substrate **11** or the handling substrate **9**.

Suitable materials for the mask layer **71** include but are not limited to a polymer, a photoresist material, and a silicone based elastomer material. For example, Polydimethyl Siloxane (PDMS), a silicone rubber, is widely recognized as a good material for soft lithography because of its flexibility, non-stick properties, and transparency to ultraviolet light. Accordingly, PDMS can be used for the mask layer **71**. Suitable materials for the under layer **73** include but are not limited to a metal, a metal alloy, a glass, a heat and chemical resistant glass such as a borosilicate glass (e.g. a **PYREX®** borosilicate glass), a silicon oxide (**SiO_2**), a silicon nitride (**Si_3N_4**), a silicon carbide (**SiC**), an aluminum oxide (**Al_2O_3**), an indium phosphide (**InP**), and a semiconductor material.

In **FIG. 26**, after the pressing, the imprint stamp **10** is withdrawn from the imprint media **70** and the imprint media **70** can be used in an imprint lithography process to imprint a target media (not shown) with the imprinted pattern I_P. On the other hand, the imprint media **70** can be used as mold upon which a target media is deposited or poured to transfer the imprinted pattern I_P to the target media. For example, a metal or

other electrically conductive material can be deposited on the imprinted pattern I_P to form the contact pads **21** and the wires **23** (as depicted in **FIGS. 20b** and **20c**). After the target media has cured or otherwise obtained a mechanically stable state, the target media can be released or peeled off of the imprinted pattern I_P. A layer of a release agent can be applied to the imprinted pattern I_P to facilitate the release of the target media from the imprinted pattern I_P. For example, a material including but not limited to a **Teflon®** can be used as the release agent.

Alternatively, in **FIG. 26**, after the pressing, the mask layer **71** can be etched **e** to further resolve or modify the features in the imprinted pattern I_P. Optionally, in **FIG. 27**, the mask layer **71** can be etched **e** all the way to a surface **73s** of the under layer **73**. The etchant can be selective to a material of the mask layer **71** so that the under layer **73** serves as an etch stop layer. Additionally, in **FIG. 27**, the under layer **73** can be etched **e** with an etchant that is selective to a material of the under layer **73** so that a remaining portion of the mask layer **71** serves as an etch mask and the imprinted pattern I_P is transferred (i.e. replicated) in the under layer **73** by the etching **e** (see I_P' in **FIG. 28**). For example, an anisotropic etching process can be used for the etching **e** of the mask layer **71** and/or the under layer **73**.

In **FIG. 29**, the imprint media **70** can be pressed into a target media **79** or the target media **79** can be deposited or poured onto the imprinted pattern I_P' so that the imprinted pattern I_P' is transferred to the target media **79**. Optionally, the target media **79** can be planarized along a line I–I to form a substantially planar surface. If the target media **79** is an electrically conductive material, then the imprinted pattern I_P' that is replicated in the target media **79** can include the wires (denoted as **23'**) and the contact pads (denoted as **21'**) as was described above in reference to **FIGS. 22a** and **22b**.

Optionally, in **FIGS. 30a** and **30b** and referring to the first embodiment of the method depicted in **FIG. 8a**, after the etching **e** of the substrate **11** at the stage **81** and prior to depositing the first layer of material **13** (see **FIGS. 10, 11,** and **12a**) at the stage **82**, at a stage **81'** a conformal layer of material **12** is deposited on the substrate **11** and conformally fills in the trenches **11t** so that a horizontal thickness $\mathbf{t_H}$ of the conformal layer of material **12** along a horizontal surface of the substrate **11** is substantially equal to a vertical thickness $\mathbf{t_V}$ of the conformal layer of material **12** along a vertical surface of the substrate **11** (i.e. along sidewall surfaces of the trenches **11t**).

One advantage to depositing the conformal layer of material **12** is that it partially fills in a feature of the substrate **11**, such as the trenches **11t**, for example. As a result, the minimum resolution λ_L of the trenches **11t** can be reduced from λ_L to a minimum feature size λ_F that is less than λ_L (i.e. $\lambda_F < \lambda_L$). Accordingly, in **FIG. 30c**, if the minimum resolution λ_L is 100 nm, then after the depositing of the conformal layer of material **12** at the stage **81'**, followed by the depositing of the first layer of material **13** at the stage **82**, then the minimum feature size λ_F will be less than 100 nm.

Consequently, the depositing of the conformal layer of material **12** can be used to reduce the minimum feature size λ_F to below to lithography limit (i.e. λ_L). As an example, if the vertical thickness $\mathbf{t_V}$ is 10.0 nm and the minimum resolution λ_L is 100 nm, then the conformal layer of material **12** can be used to make contact pads **21** (see **FIGS. 22a** and **22b**) that have a minimum feature size λ_F of 80 nm (i.e. 100 nm − [2 * 10 nm] = 80 nm) that is less than the minimum resolution λ_L of 100 nm. More than one conformal layer of material **12** can be deposited to further decrease the minimum feature size λ_F.

In **FIG. 31a**, in the second embodiment of the method as depicted in **FIG. 8b** includes, at a stage **92**, depositing a base layer of material **14** on a substrate **11**. Preferably, the base layer of material **14** is deposited on a substantially planar surface

11s of the substrate **11**. At a stage **93**, the base layer of material **14** is patterned with an etch mask **25** as was described above in reference to **FIG. 10**. At a stage **94**, the base layer of material **14** is etched **e** to form a pattern (see **FIG. 31b**) in the base layer of material **14**. The pattern can include trenches **14t** formed in the base layer of material **14** and extending inward of a surface **14s**. The patterns formed will have a feature size that is greater than or equal to the minimum resolution $\boldsymbol{\lambda_L}$.

In **FIG. 31d**, at a stage **95**, a first layer of material **13** can be deposited. The first layer of material is one of a plurality of layers of material that will be deposited in the deposition order $\mathbf{D_O}$ and subsequently patterned and etched **e** as was described above in reference to **FIGS. 12b** through **19c**. Optionally, at a stage **95'**, the first layer of material **13** can be planarized as was described above to form a substantially planar surface **13s** along a line I–I.

Moreover, in **FIG. 31c**, at a stage **94'**, after the etching at the stage **94** and prior to the depositing of the first layer of material **13** at the stage **95**, a conformal layer of material **12** is deposited on the base layer of material **14** and conformally fills in the trenches **14t** so that a horizontal thickness $\mathbf{t_H}$ of the conformal layer of material **12** along a horizontal surface of the base layer of material **14** is substantially equal to a vertical thickness $\mathbf{t_V}$ of the conformal layer of material **12** along a vertical surface of the base layer of material **14** (i.e. along sidewall surfaces of the trenches **14t**) as was described above in reference to **FIGS. 30a** through **30c**.

In the second embodiment of the method as depicted in **FIG. 8b**, the stages **96** through **103** and optionally including a stage **101'**, are substantially identical to the stages **83** through **90** of **FIG. 8a** as described above in reference to **FIGS. 12b** through **23b**. Consequently, after the application specific imprint pattern **40** is completely formed at a stage **101**, followed by the segmenting at a stage **102** and the selectively etching at a stage **103**, an imprint stamp **10** is formed as depicted in **FIGS. 20a** and **20b**.

Etching processes that are well known in the microelectronics art can be used to etch the layers of material (**12, 13, 15**) and/or the substrates (**11, 14**). For example, an etch process including but not limited to a wet etch, a dry etch, a plasma etch, and a reactive ion etch (RIE), can be used. The etching process can include an anisotropic etch material or an isotropic etch material.

It may be desirable in some applications to not pattern and etch one or more of the layers of material (**13, 15**) after the depositing stages. Instead, the layer may be planarized so that the next layer in the deposition order $\mathbf{D_O}$ is deposited on a substantially planar surface. For example, after one of the layers is planarized, the next layer in the deposition order $\mathbf{D_O}$ may also not be patterned or etched so that it is also a substantially planar layer. As a result the planar layers can be used to impart a space between subsequent layers in the deposition order $\mathbf{D_O}$ that will be patterned and etched to form variations in the topography of those subsequent layers.

Suitable materials for the layers of material (**12, 13, 15**) include but are not limited to those set forth in **TABLE 1** below.

Materials for the layers of material (12, 13, 15)
Silicon Oxide (**SiO_2**)
Silicon Nitride (**Si_3N_4**)
Polysilicon (**α-Si**) including A Doped Polysilicon
A Metal
A Metal Alloy
Silicon Oxynitride (**Si_2N_2O**)
Silicon Carbide (**SiC**)
Diamond like Carbon (**C**)
A Silicide
Tetraethylorthosilicate (**TEOS**)
A Boron (**B**) doped Tetraethylorthosilicate (**BSG**)
A Phosphorus (**P**) doped Tetraethylorthosilicate (**PSG**)
A Boron (**B**) and Phosphorus (**P**) doped Tetraethylorthosilicate (**BPSG**)
A Polymer
A Photoresist Material
A Dielectric Material
An Electrically Conductive Material

TABLE 1

It may be desirable in some applications to not pattern and etch one or more of the layers of material (**13, 15**) after the depositing stages. Instead, the layer may be planarized so that the next layer in the deposition order $\mathbf{D_O}$ is deposited on a substantially planar surface. For example, after one of the layers is planarized, the next

layer in the deposition order $\mathbf{D_O}$ may also not be patterned or etched so that it is also a substantially planar layer. As a result the planar layers can be used to impart a space between subsequent layers in the deposition order $\mathbf{D_O}$ that will be patterned and etched to form variations in the topography of those subsequent layers.

Deposition processes that are well understood in the microelectronics art can used to deposit the layers of material (**13, 15**). For example, a process including but not limited to chemical vapor deposition (CVD), plasma enhanced chemical vapor deposition (PECVD), sputtering, and atomic layer deposition (ALD) can be used to deposit the layers of material (**13, 15**).

A computer aided design (CAD) program can be used to create the application specific imprint pattern **40**. For example, a layout tool used in the fabrication of microelectronic circuits, such as microprocessors, can be used to design a layout for the various layers of material (**12, 13, 15**). After the layout is complete, a plurality of photomasks can be generated using data from the layout tool and those photomasks can be used to pattern the layers of material by exposing a photoresist material deposited on the layer. The photoresist can then be developed to render the pattern in an etch mask **25**, followed by etching the layer to form a portion of the application specific imprint pattern **40**. The application specific imprint pattern **40** formed on the imprint stamp **10** can comprise any pattern and is not to be construed as being limited to the wires **23** and contact pads **21** as described herein for purposes of illustration only. Accordingly, each application will determine the actual shape and complexity of the patterns and features of the application specific imprint pattern **40**.

Although several embodiments of the present invention have been disclosed and illustrated, the invention is not limited to the specific forms or arrangements of parts so described and illustrated. The invention is only limited by the claims.